



# Lepton Flavor Violation at Belle II

Claudia Cecchi  
University of Perugia and INFN  
On behalf of the Belle II Collaboration

NuFact 2015, Rio de Janeiro, Brasil

## Outline:

- Introduction
- Search for LFV at BELLE
- Perspectives for BelleII experiment
- Conclusions

# Introduction

- LFV is established but only in neutral neutrino, what about charged partners?
- Lepton Flavor Violation (LFV) in charged leptons has negligible probability in the Standard Model (SM) even including neutrino oscillation
- LFV is a clear signature of New Physics  
Many extensions of the SM predict LFV decays, B.F. can be enhanced as high as current experimental sensitivity  $\mathcal{O}(10^{-8})$
- most powerful searches in muons and  $\tau$ 's: taus has a "per particle" advantage GIM suppression is smaller than in muons; but high statistics in muon beams.
- Tau is the heaviest lepton:
  - expect strong coupling to NP
  - many possible LFV decays  $\rightarrow$  Tau's are ideal probe of NP

# Tau Lepton Flavor Violation

$$Br(\tau \rightarrow \mu\gamma)_{SM} \propto \left( \frac{\delta m_\nu^2}{m_W^2} \right)^2 < 10^{-40}$$

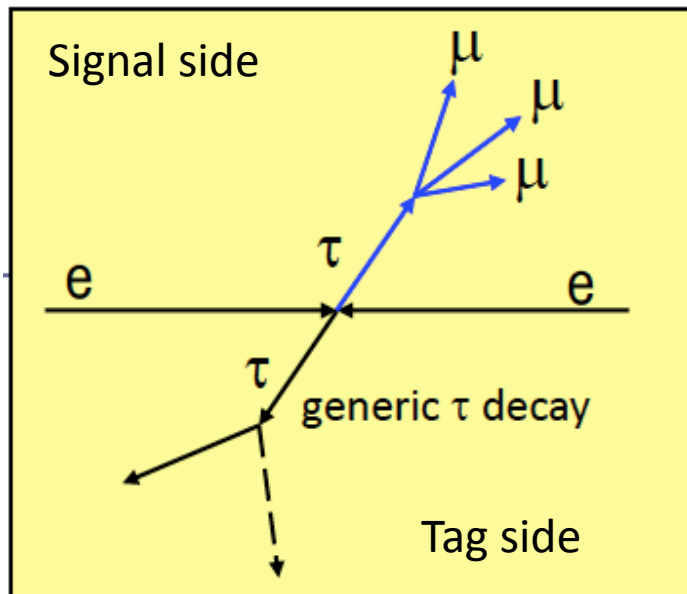
(X.Pham, EPJC8 513(1999))

**Ratio of Tau LFV decay BF: discrimination of NP models**  
**JHEP 0705, 013(2007), PLB54 252 (2002)**

	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z' boson
$\left( \frac{\tau \rightarrow \mu\mu\mu}{\tau \rightarrow \mu\gamma} \right)$	$\sim 2 \times 10^{-3}$	0.06~0.1	0.4~2.3	$\sim 16$
$\left( \frac{\tau \rightarrow \mu ee}{\tau \rightarrow \mu\gamma} \right)$	$\sim 1 \times 10^{-2}$	$\sim 1 \times 10^{-2}$	0.3~1.6	$\sim 16$
$Br(\tau \rightarrow \mu\gamma)$	$< 10^{-7}$	$< 10^{-10}$	$< 10^{-10}$	$< 10^{-9}$

# Analysis strategy

Tag side: one prong decay + neutrino B.R. 85%  
Signal side: full reconstruction

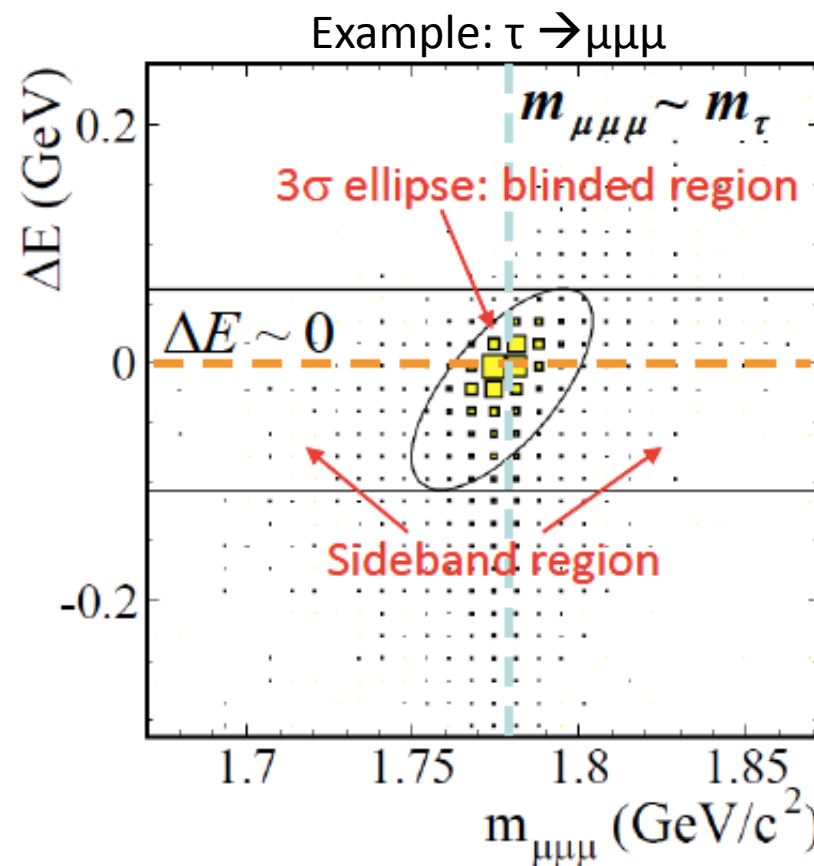


Extract signal from  $M_\tau$  vs  $\Delta E$

$$M_\tau = \sqrt{E_{\mu\mu\mu}^2 - p_{\mu\mu\mu}^2}$$

$$\Delta E = E_{\mu\mu\mu}^{CM} - E_{beam}^{CM}$$

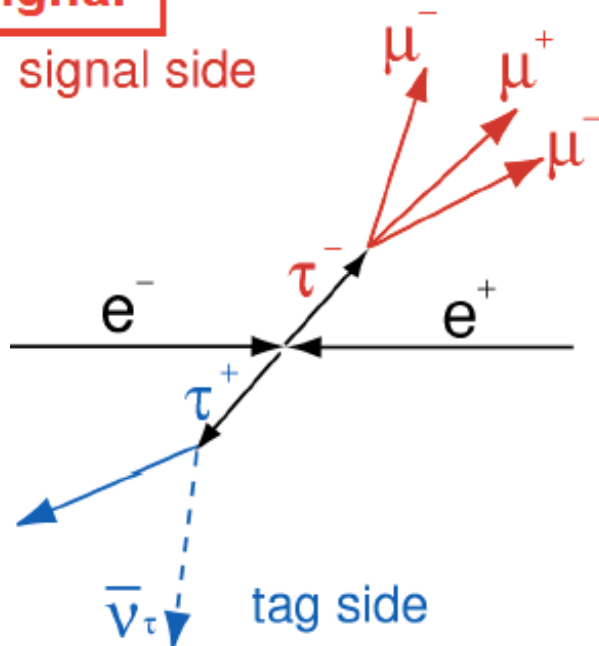
- Blind analysis
- Background estimation from data and MC in the sidebands



# Background contamination

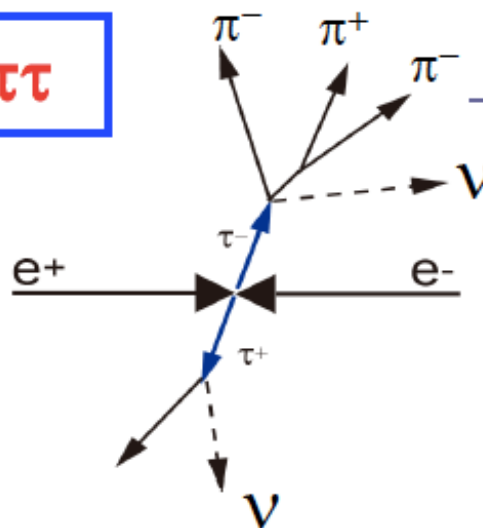
**signal**

signal side



- Neutrino(s) in tag side
- Particle ID

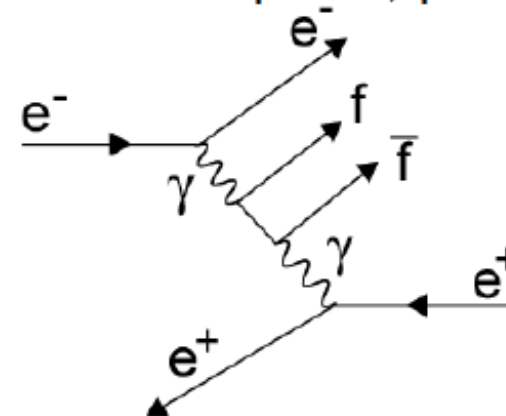
**$\tau\tau$**



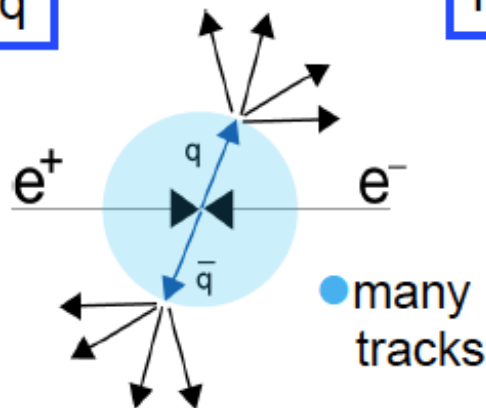
- Neutrinos in both sides
- Missing energy in signal side

**2photon process**

f=leptons, quarks

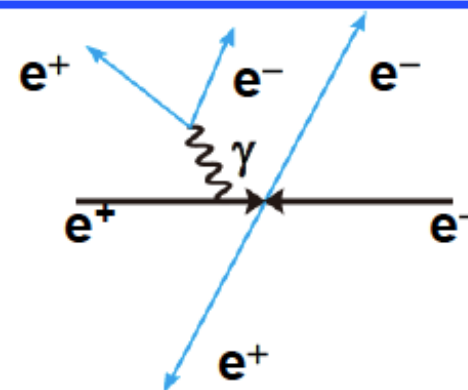


**$q\bar{q}$**



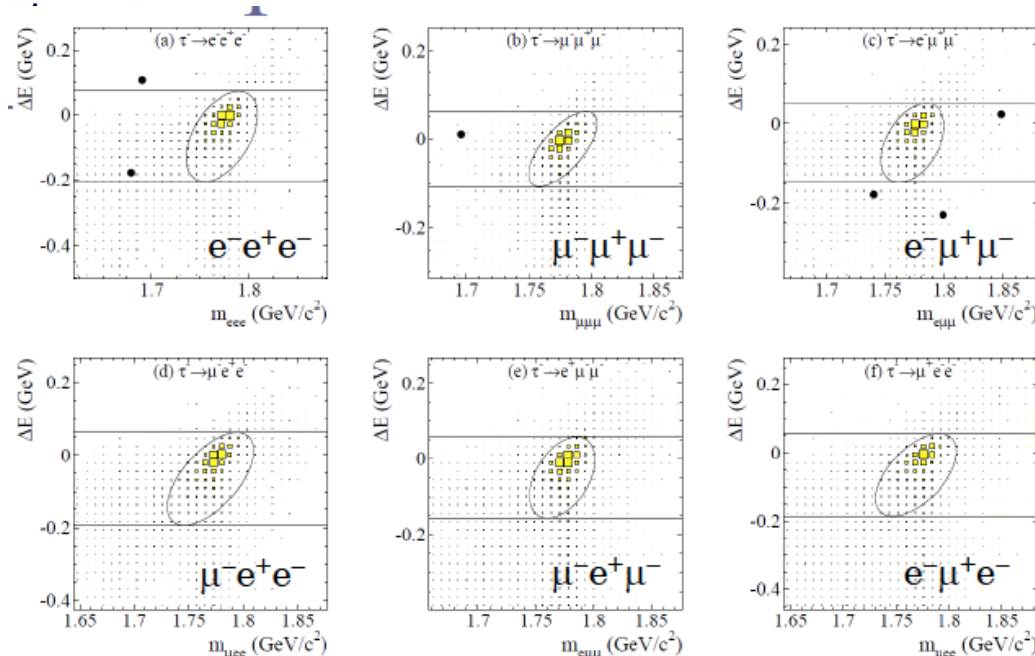
- many tracks

**radiative Bhabha process**



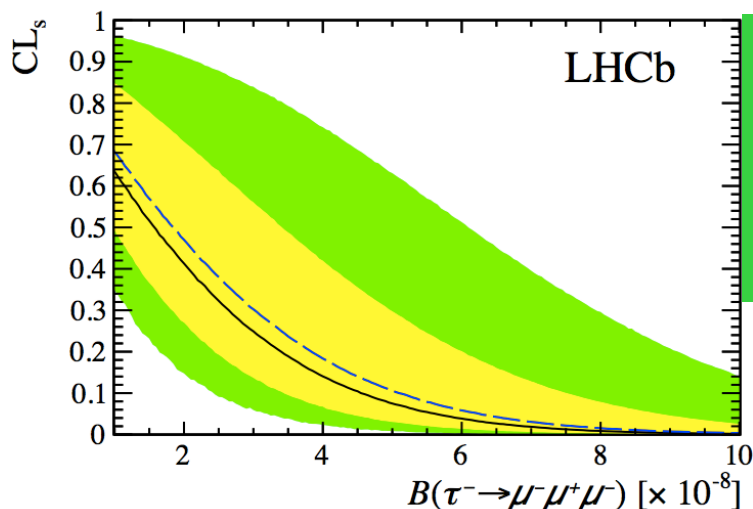


# $\tau \rightarrow 3 \text{ leptons}$



BELLE data set: 782 fb<sup>-1</sup>  
No events have been found in the signal region

Very good lepton ID → almost no bckgnd  
Expected bckgnd events : 0.01 - 0.21



LHCb: 1 fb<sup>-1</sup>@7TeV + 2fb<sup>-1</sup>@8TeV  
**Br < 4.6 × 10<sup>-8</sup> @ 90% C.L.**  
JHEP 02 (2015) 121

**Br < (1.5-2.7) × 10<sup>-8</sup> @ 90% C.L.**  
(Phys. Lett. B687, 139 (2010)).

Mode	$\varepsilon$ (%)	$N_{BG}^{EXP}$	$\sigma_{syst}$ (%)	UL (×10 <sup>-8</sup> )
$e^-e^+e^-$	6.0	$0.21 \pm 0.15$	9.8	<b>2.7</b>
$\mu^-\mu^+\mu^-$	7.6	$0.13 \pm 0.06$	7.4	<b>2.1</b>
$e^-\mu^+\mu^-$	6.1	$0.10 \pm 0.04$	9.5	<b>2.7</b>
$\mu^-e^+e^-$	9.3	$0.04 \pm 0.04$	7.8	<b>1.8</b>
$\mu^-e^+\mu^-$	10.1	$0.02 \pm 0.02$	7.6	<b>1.7</b>
$e^-\mu^+e^-$	11.5	$0.01 \pm 0.01$	7.7	<b>1.5</b>

$$\tau \rightarrow l h h'$$

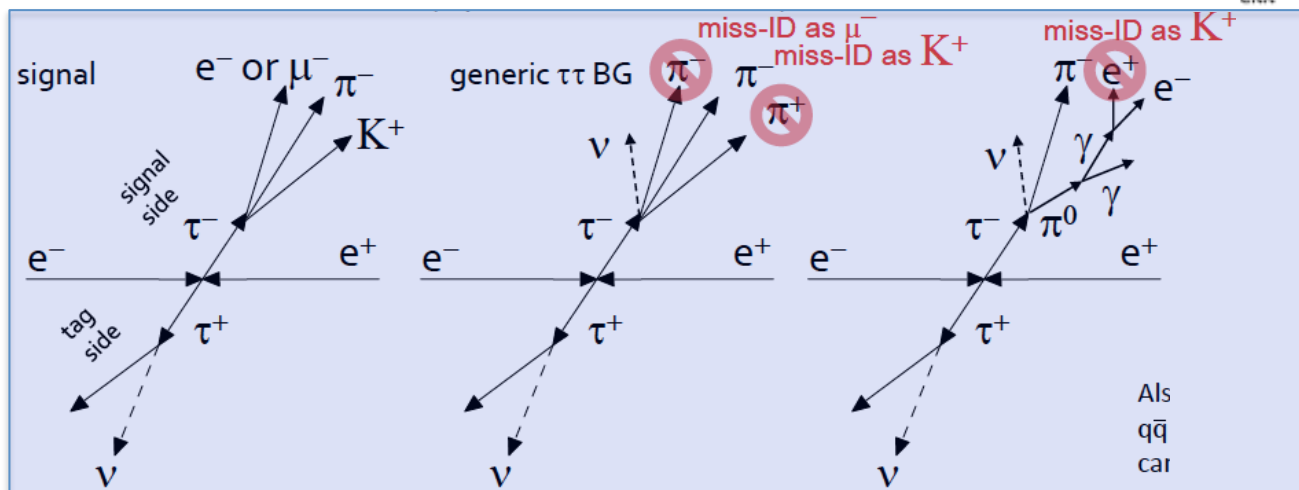
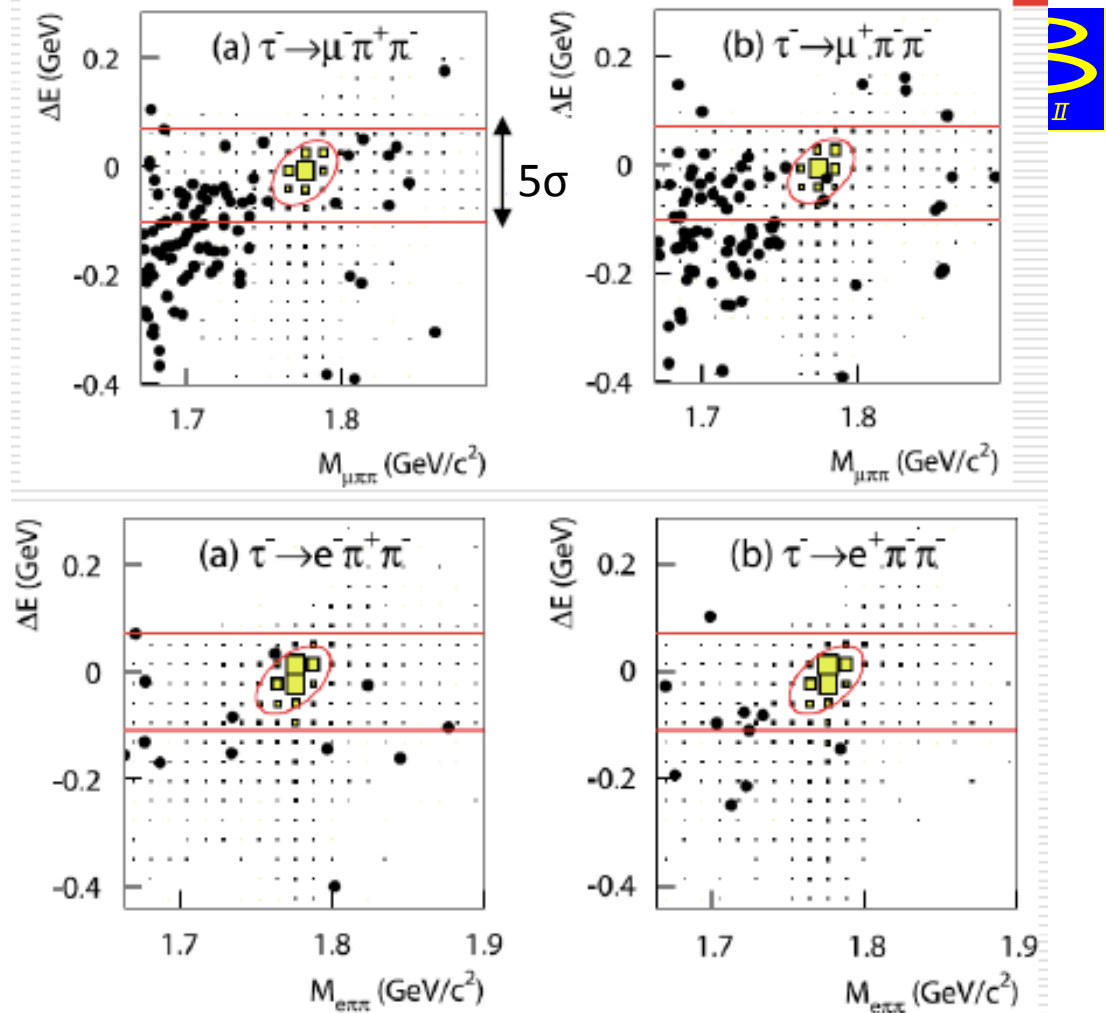
BELLE data set: 854 fb<sup>-1</sup>

14 decay modes

$h, h' = \pi^{+-}, K^{+-}$

$\tau^- \rightarrow l^- h^+ h'^-$  (8 modes)

$\tau^- \rightarrow l^+ h^- h'^-$  (6 modes)





$$\tau \rightarrow l h h'$$

Mode	$\varepsilon$ (%)	$N_{BG}$	$N_{obs}$	$\mathcal{B}$ ( $10^{-8}$ )
$\tau^- \rightarrow \mu^- \pi^+ \pi^-$	5.83	$0.63 \pm 0.23$	0	2.1
$\tau^- \rightarrow \mu^+ \pi^- \pi^-$	6.55	$0.33 \pm 0.16$	1	3.9
$\tau^- \rightarrow e^- \pi^+ \pi^-$	5.45	$0.55 \pm 0.23$	0	2.3
$\tau^- \rightarrow e^+ \pi^- \pi^-$	6.56	$0.37 \pm 0.18$	0	2.0
$\tau^- \rightarrow \mu^- K^+ K^-$	2.85	$0.51 \pm 0.18$	0	4.4
$\tau^- \rightarrow \mu^+ K^- K^-$	2.98	$0.25 \pm 0.13$	0	4.7
$\tau^- \rightarrow e^- K^+ K^-$	4.29	$0.17 \pm 0.10$	0	3.4
$\tau^- \rightarrow e^+ K^- K^-$	4.64	$0.06 \pm 0.06$	0	3.3
$\tau^- \rightarrow \mu^- \pi^+ K^-$	2.72	$0.72 \pm 0.27$	1	8.6
$\tau^- \rightarrow e^- \pi^+ K^-$	3.97	$0.18 \pm 0.13$	0	3.7
$\tau^- \rightarrow \mu^- K^+ \pi^-$	2.62	$0.64 \pm 0.23$	0	4.5
$\tau^- \rightarrow e^- K^+ \pi^-$	4.07	$0.55 \pm 0.31$	0	3.1
$\tau^- \rightarrow \mu^+ K^- \pi^-$	2.55	$0.56 \pm 0.21$	0	4.8
$\tau^- \rightarrow e^+ K^- \pi^-$	4.00	$0.46 \pm 0.21$	0	3.2

← Lowest U.L.

← Highest U.L.

1 event in the signal region in  $\mu^+ \pi^- \pi^-$  and in  $\mu^- \pi^+ K^-$   
expected bckgnd events 0.06 - 0.72

Improvement w.r.t. to previous limit by a factor of about 1.8

$Br < (2.0-8.6) \times 10^{-8}$  @ 90% C.L.  
(Phys. Lett. B719, 346 (2013))

# $T \rightarrow \Lambda h, \bar{\Lambda} h \ (h=\pi, K)$

BELLE data set: 904 fb<sup>-1</sup>  
4 decay modes

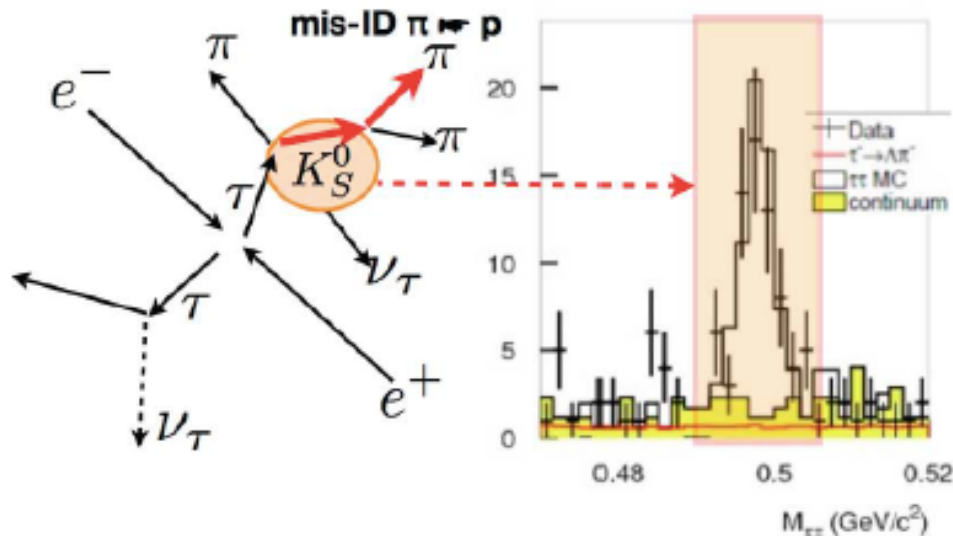
$h = \pi, K$

$T^- \rightarrow \bar{\Lambda} h^-$  (B-L conserving)

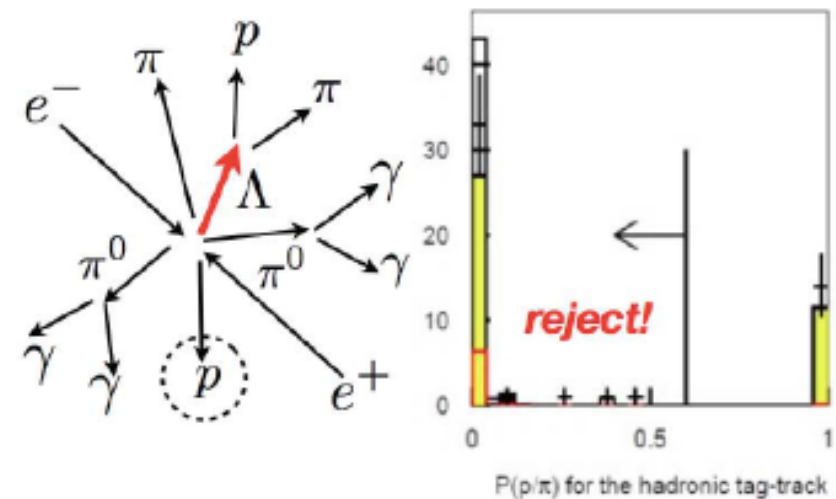
$T^- \rightarrow \Lambda h^-$  (B-L violating)

	$\tau^- \rightarrow \bar{\Lambda} \pi^-, K^-$ $\bar{p} \pi^+$				$\tau^- \rightarrow \Lambda \pi^-, K^-$ $p \pi^-$		
	$\tau^-$	$\bar{\Lambda}$	$\pi^- K^-$		$\tau^-$	$\Lambda$	$\pi^- K^-$
B	0	-1	0	B	0	1	0
L	1	0	0	L	1	0	0
B-L	-1	-1	0	B-L	1	1	0
(B-L) conserving				(B-L) violating			

$K_S$  VETO



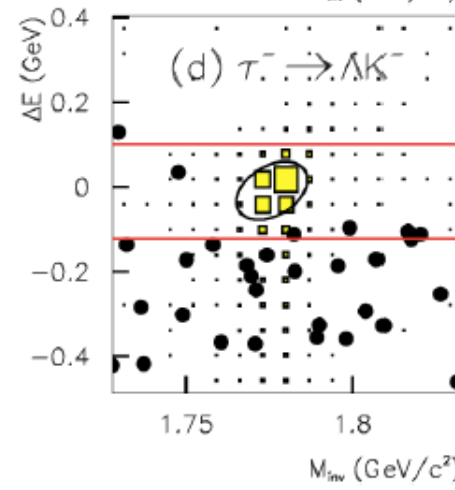
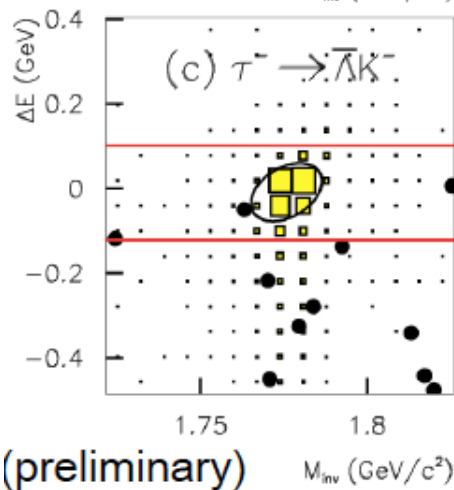
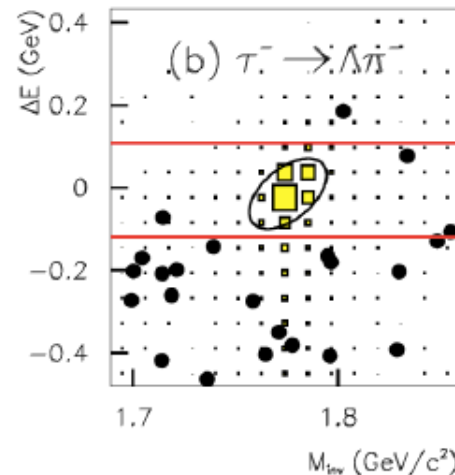
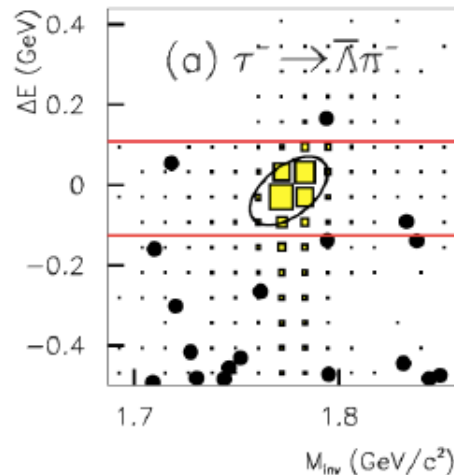
PROTON VETO tag side



# $\tau^- \rightarrow \Lambda h, \bar{\Lambda} h \quad (h=\pi, K)$

No events have been found in the signal region

Expected bckgnd events :  
0.21 - 0.42



Mode	$\epsilon$ (%)	$N_{BG}$	$N_{obs}$	$\mathcal{B} (10^{-8})$
$\tau^- \rightarrow \bar{\Lambda} \pi^-$	4.80	$0.21 \pm 0.15$	0	2.8
$\tau^- \rightarrow \bar{\Lambda} \pi^-$	4.39	$0.31 \pm 0.18$	0	3.0
$\tau^- \rightarrow \bar{\Lambda} K^-$	4.11	$0.31 \pm 0.14$	0	3.1
$\tau^- \rightarrow \Lambda K^-$	3.16	$0.42 \pm 0.19$	0	4.2

U.L @ 90% C.L.

$Br(\tau^- \rightarrow \bar{\Lambda} \pi^-) < 2.8 \times 10^{-8}$

$Br(\tau^- \rightarrow \bar{\Lambda} K^-) < 3.1 \times 10^{-8}$

$Br(\tau^- \rightarrow \Lambda \pi^-) < 3.0 \times 10^{-8}$

$Br(\tau^- \rightarrow \Lambda K^-) < 4.2 \times 10^{-8}$

B-L cons.

B-L viol.

(preliminary)

$$\tau \rightarrow \mu \gamma$$

BELLE data set: 535 fb<sup>-1</sup>

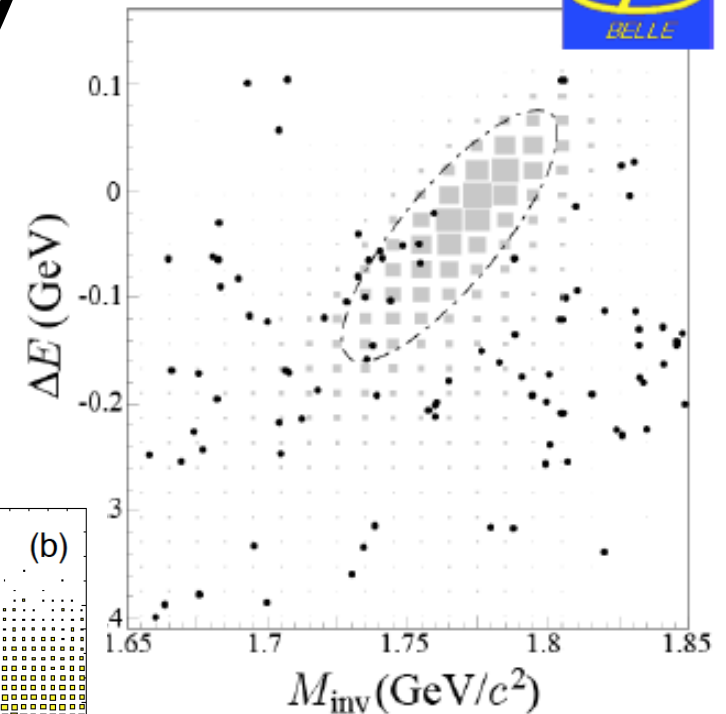
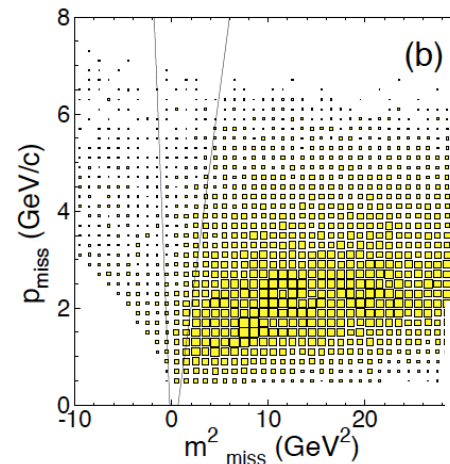
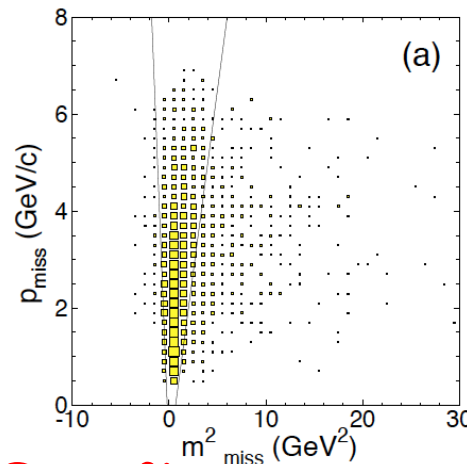
Main backgrounds:

$\tau \rightarrow \mu \nu \nu + \text{ISR}$

$\tau \rightarrow \pi \nu$  (mis identification of  $\pi$  with  $\mu$ )

94 events in the 5 $\sigma$  signal region

Expected backgnd:  $88.4 \pm 7.4$



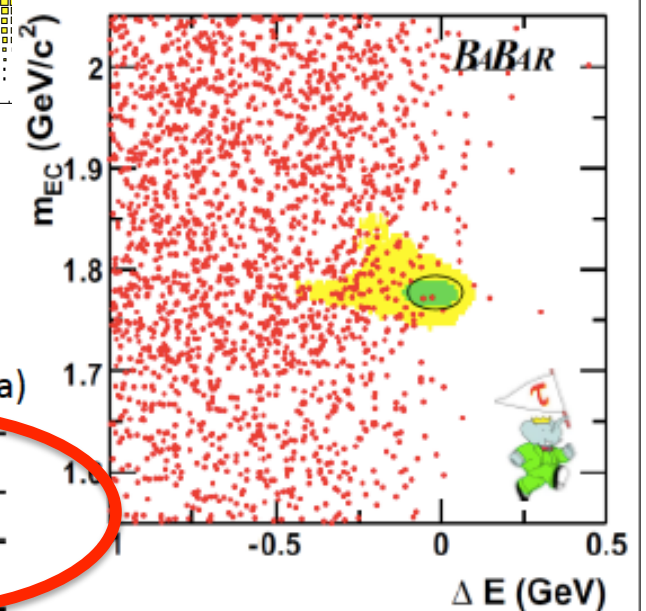
$\text{Br} < 4.5 \times 10^{-8}$  @ 90% C.L.

$7.8 \times 10^{-8}$  expected

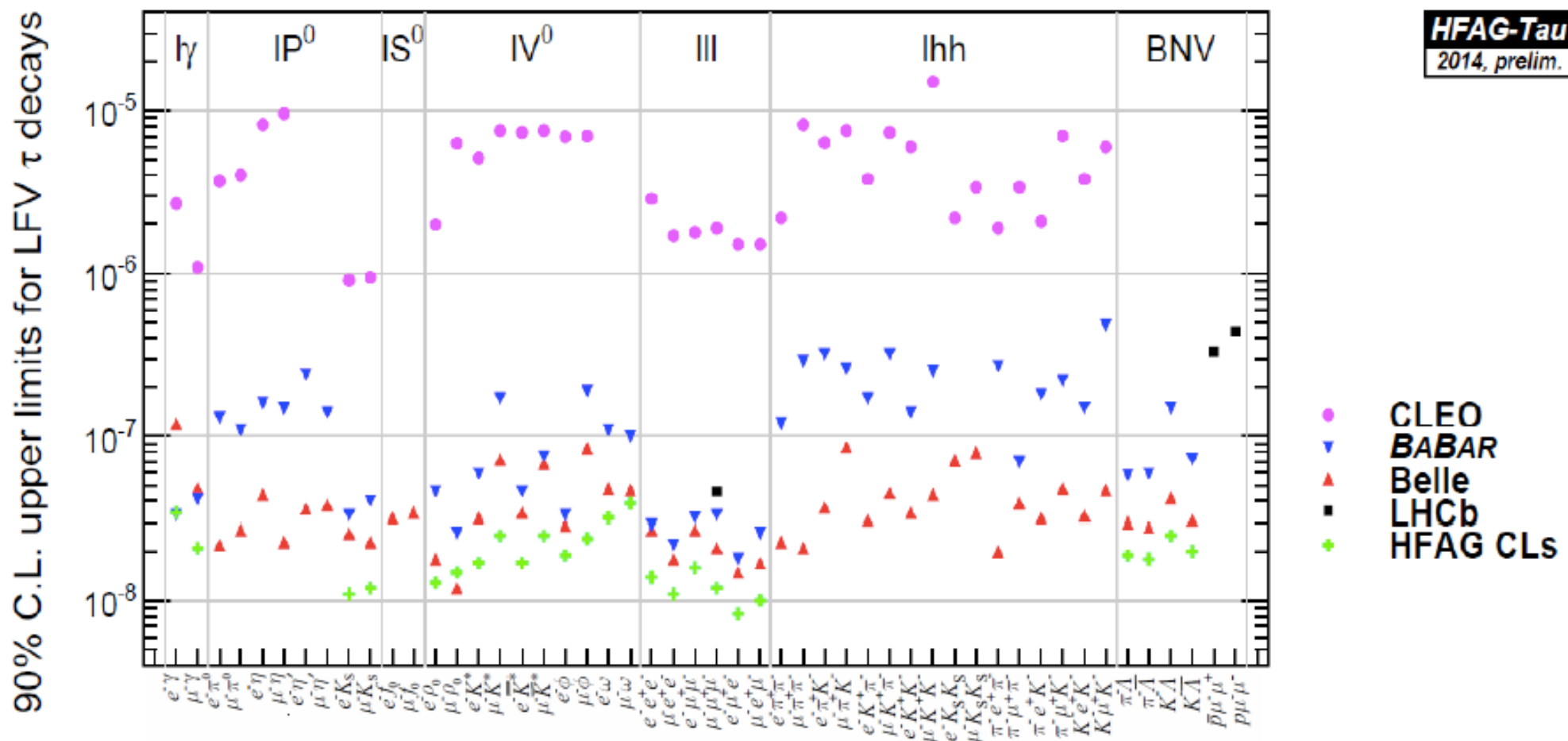
(Phys. Lett. B66, 16 (2008))

BaBar: Data: 482M  $\tau$  pairs (including  $\Upsilon(2,3S)$  data)

Decay modes	2 $\sigma$ signal ellipse		$\epsilon$ (%)	UL ( $\times 10^{-8}$ )	
	obs	exp		obs	exp
$\tau^\pm \rightarrow \mu^\pm \gamma$	2	$3.6 \pm 0.7$	$6.1 \pm 0.5$	4.4	8.2



# Summary of recent tau LFV searches

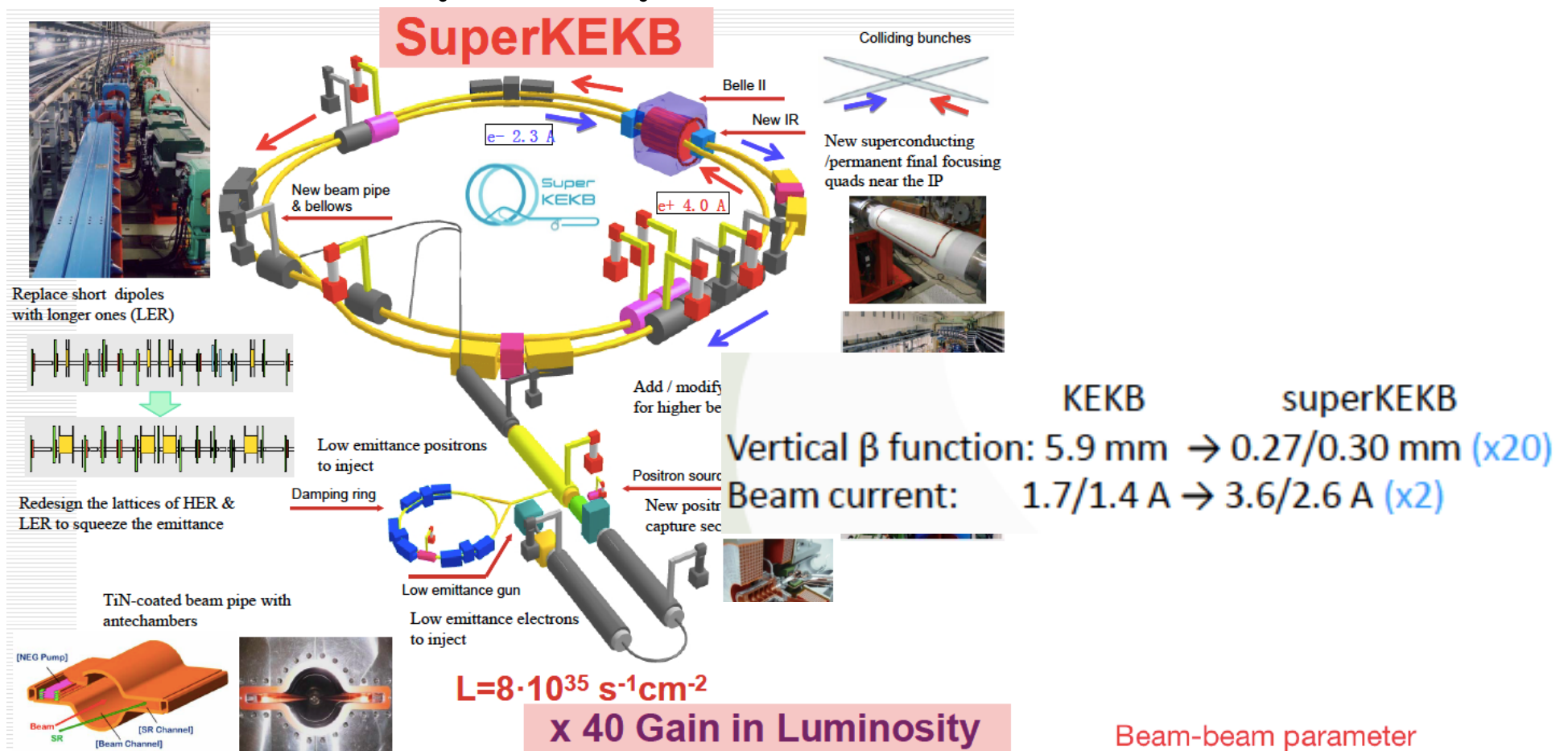


48 decay modes investigated - 100 x more sensitivity w.r.t. CLEO results

LHCb results on 3 leptons comparable to B-factories



# Future perspectives: Belle II



## NANO-BEAM scheme:

- Smaller  $\beta_y^*$
- Increase beam current
- Increase  $\xi_y$

Lorentz factor

Beam current

Beam-beam parameter

$$L = \frac{\gamma_{e\pm}}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_x^*} \left( \frac{I_{e\pm} \xi_y^{e\pm}}{\beta_y^*} \right) \frac{R_L}{R_{\xi_y}} \right)$$

Classical electron radius

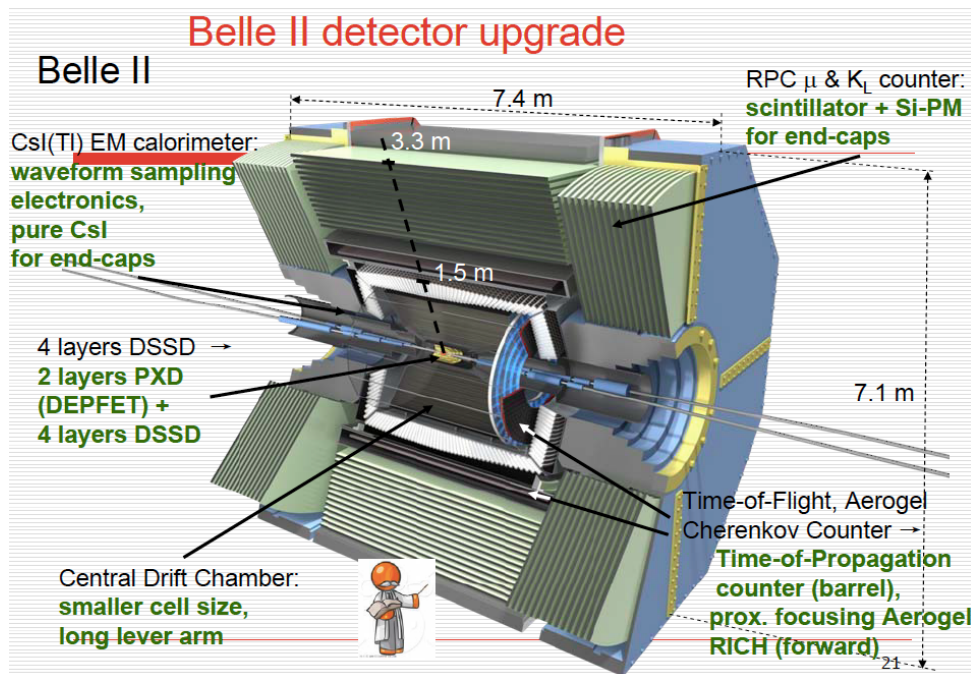
Beam size ratio@IP  
1 ~ 2 % (flat beam)

Lumi. reduction factor (crossing angle) & Tune shift reduction factor (hour glass effect) 0.8 ~ 1 (short bunch)

Vertical beta function@IP



# Detector upgrade



**Critical issues @  $8 \times 10^{35} \text{ s}^{-1} \text{ cm}^{-2}$**

**-Higher background (x10-20)**

- radiative Bhabha dominate
- radiation damage, occupancy
- pile-up in ECL

**-Higher event rates (x10)**

- higher trigger rates (0.5 → 3KHz)
- DAQ

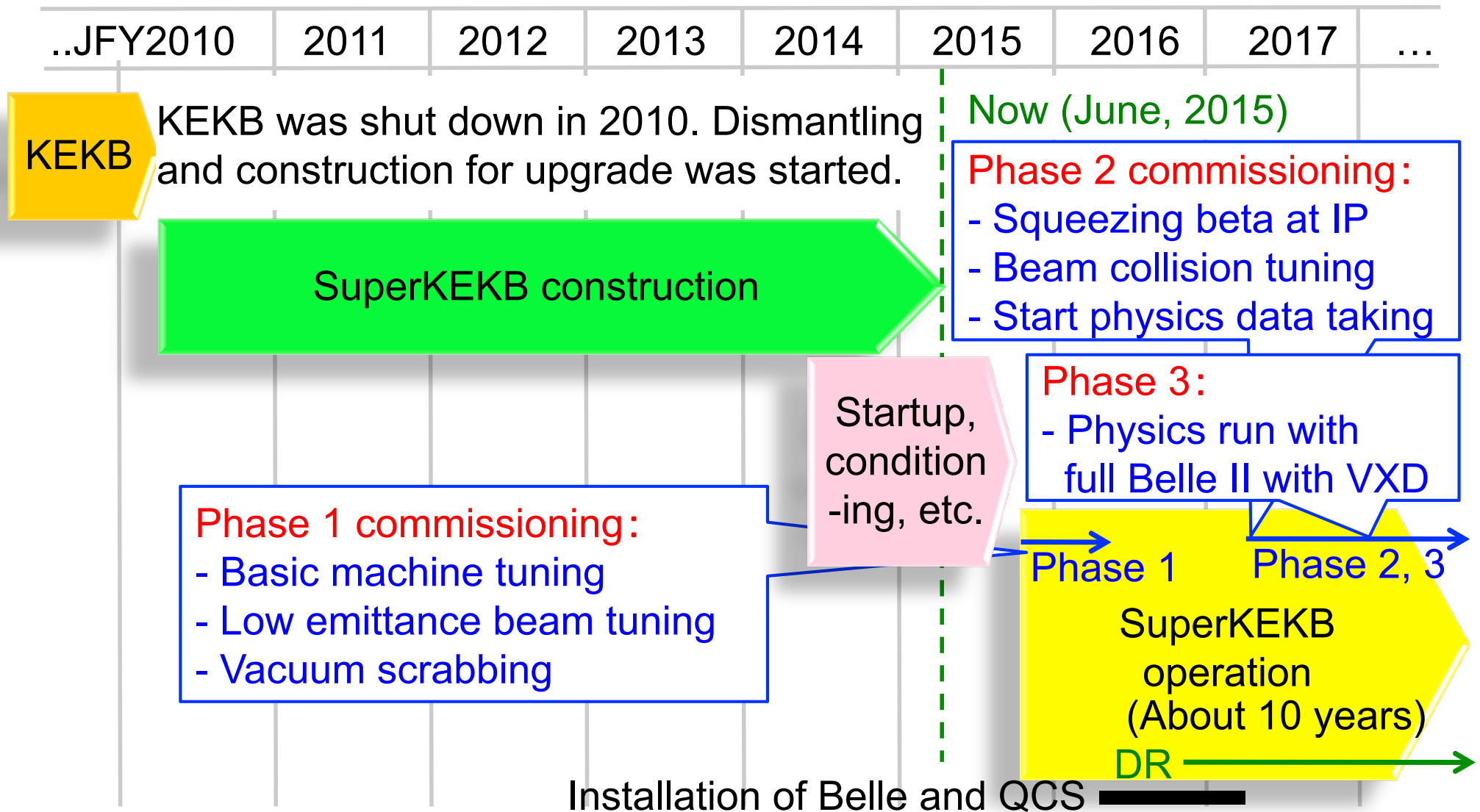
**-IMPROVEMENTS**

- hermeticity ( $K\pi$ -ID  $\mu$ -ID endcap)
- IP and secondary vertex resolution
- $K_S$  and  $\pi^0$  efficiency
- $K/\pi$  separation
- $\mu$ -ID and PID endcaps

**TDR arXiv: 10110352**

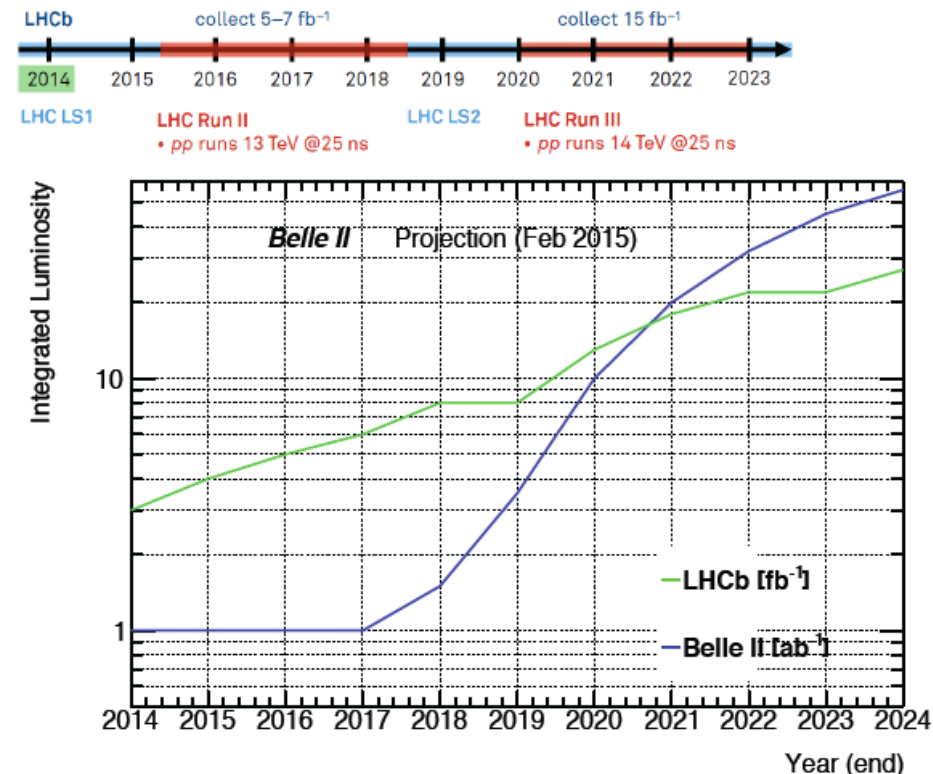
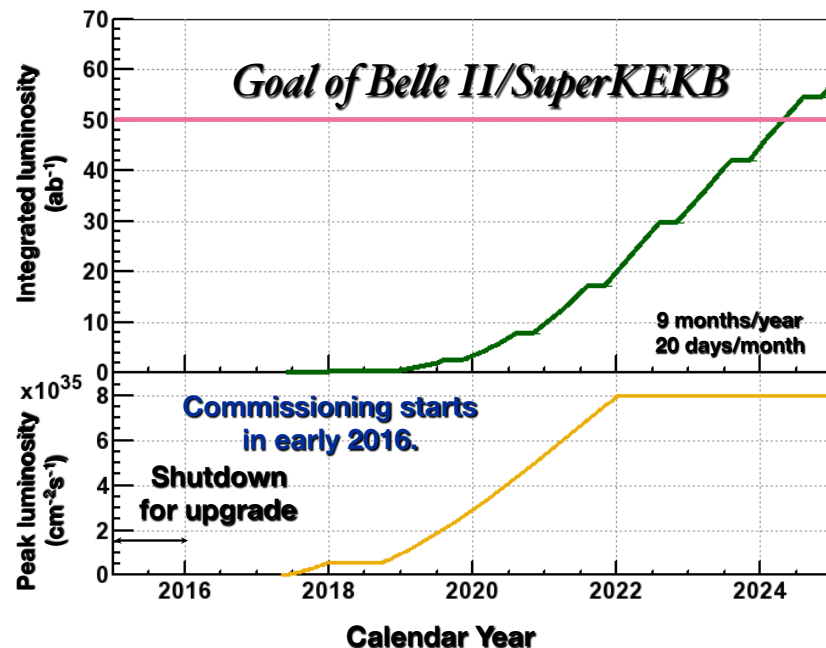
# Schedule

- ✓ SuperKEKB construction is finished
- ✓ startup for Phase 1 are in progress.



# Luminosity profile and LHCb

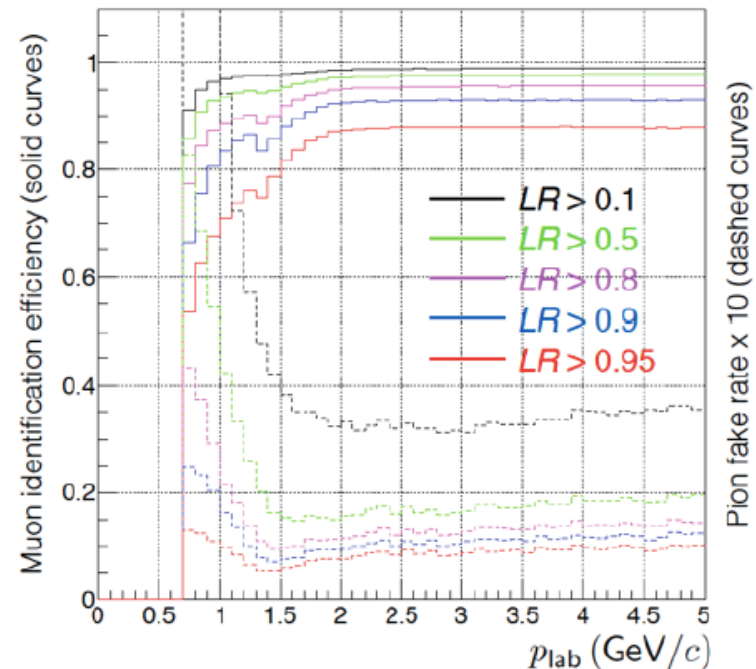
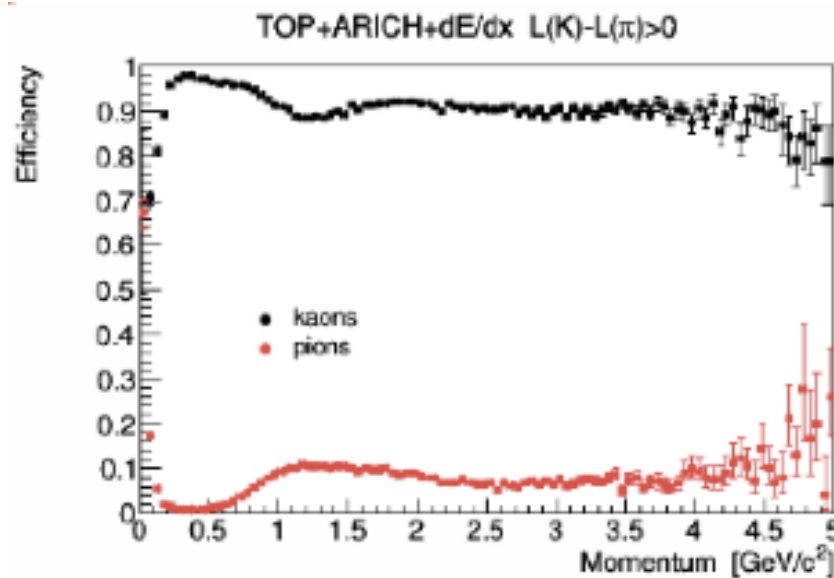
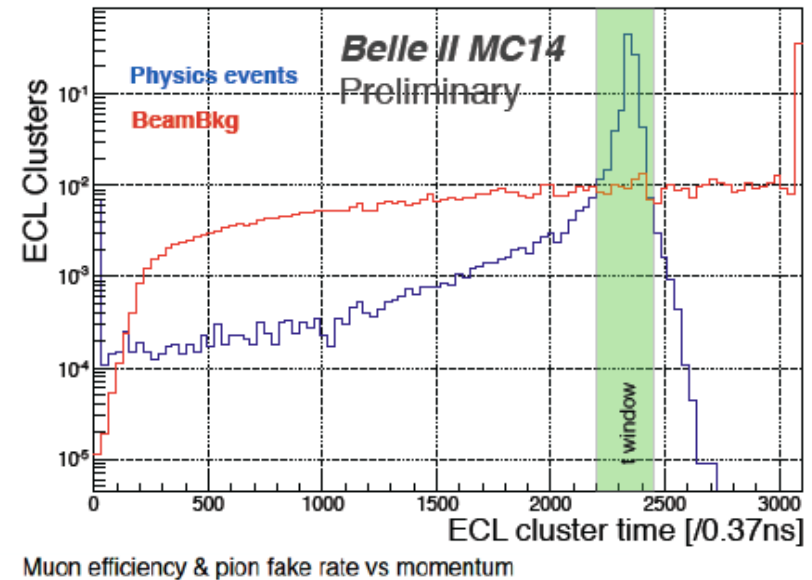
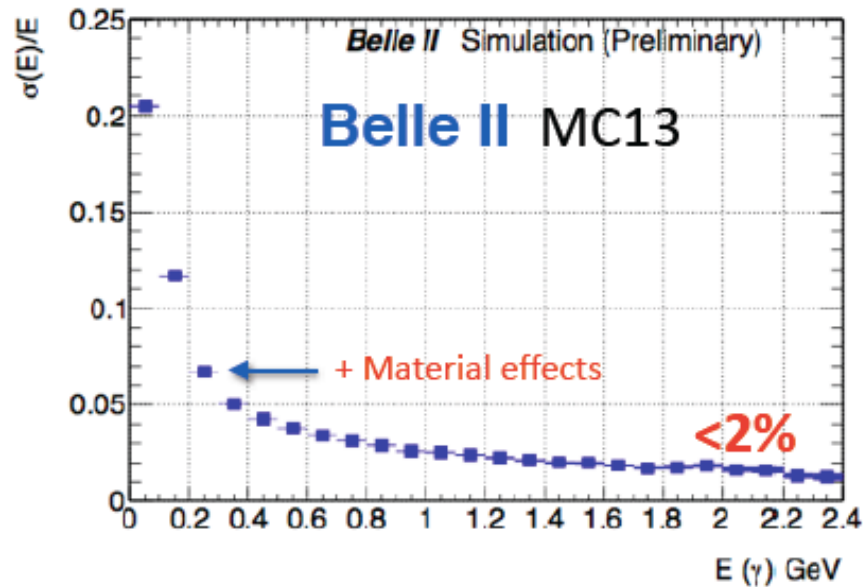
## SuperKEKB luminosity projection



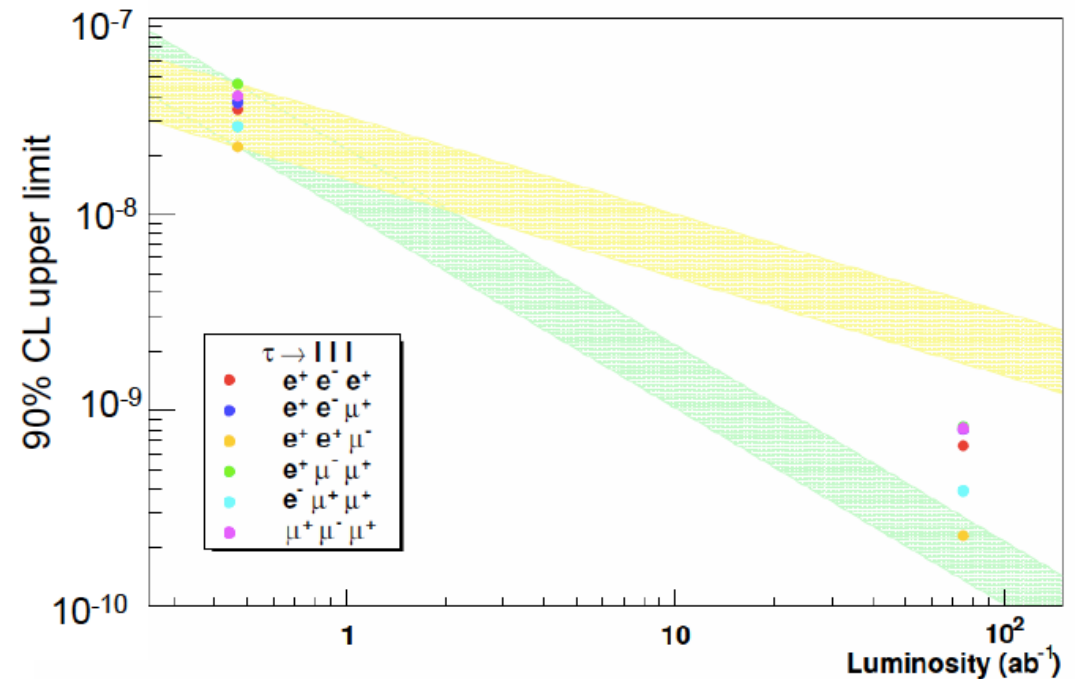
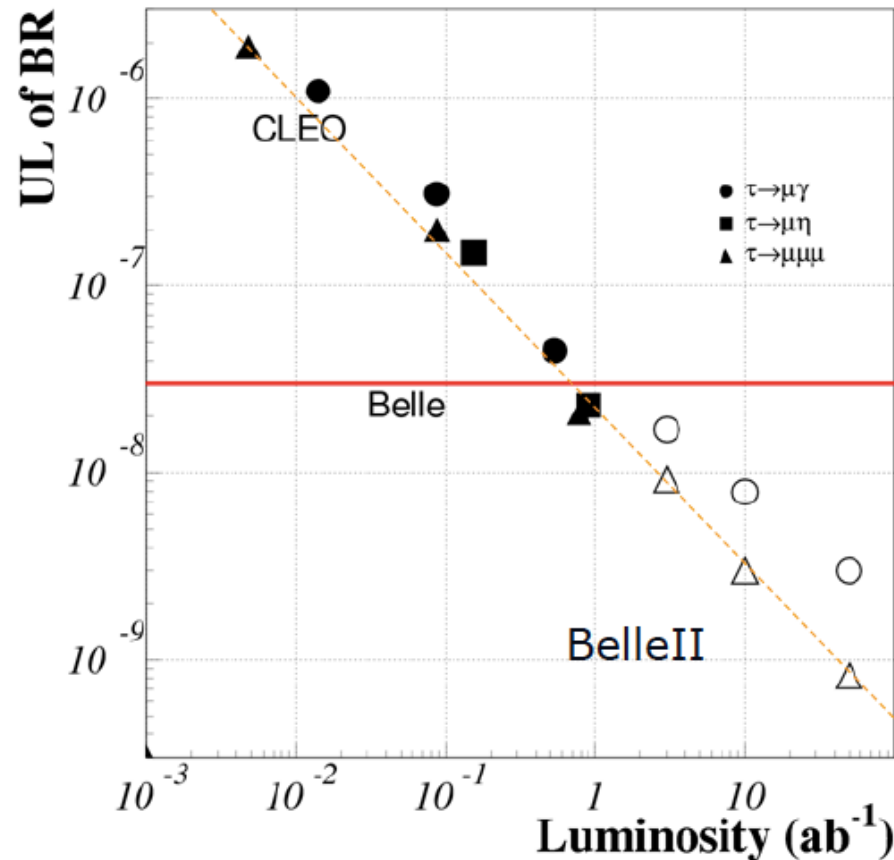
50  $\text{ab}^{-1}$  in 2023-2024  
O ( $10^{11}$ ) Tau sample

Golden modes are different for the two experiments and also cross sections!!!

# Ingredients for the future



# Perspectives for LFV



The no-background regime improves as  $1 / \int L dt$

If there are background events, the improvement is  $1 / \sqrt{\int L dt}$

$\tau \rightarrow \mu \gamma$  (no bckgnd free) expected limite  $O(10^{-9})$   
 $\tau \rightarrow \mu \mu \mu$  (bckgnd free) expected limit  $O(10^{-10})$

**The full range of  $\tau$  LFV is only accessible at a Super B factory**

# Conclusions

**Tau lepton is a good probe for NP searches like LFV**  
**B factories produced a huge data sample  $O(10^9)$  tau pairs**

## **BELLE:**

- 48 LFV decay modes have been investigated 100x sensitive results w.r.t. CLEO
- 90% C.L. Upper Limits have been set in  $O(10^{-8})$
- $\tau \rightarrow \mu\gamma/e\gamma$  will be updated with the full data set

## **BELLEII:**

- machine upgrade is finished and detector upgrade is ongoing smoothly
  - detector improvement will play a key role in background elimination and reduction of systematic effects
- start of full physics 2018, reach  $50 \text{ ab}^{-1}$  by 2023-2024
- LFV will be probed up to  $O(10^{-9} - 10^{-10})$

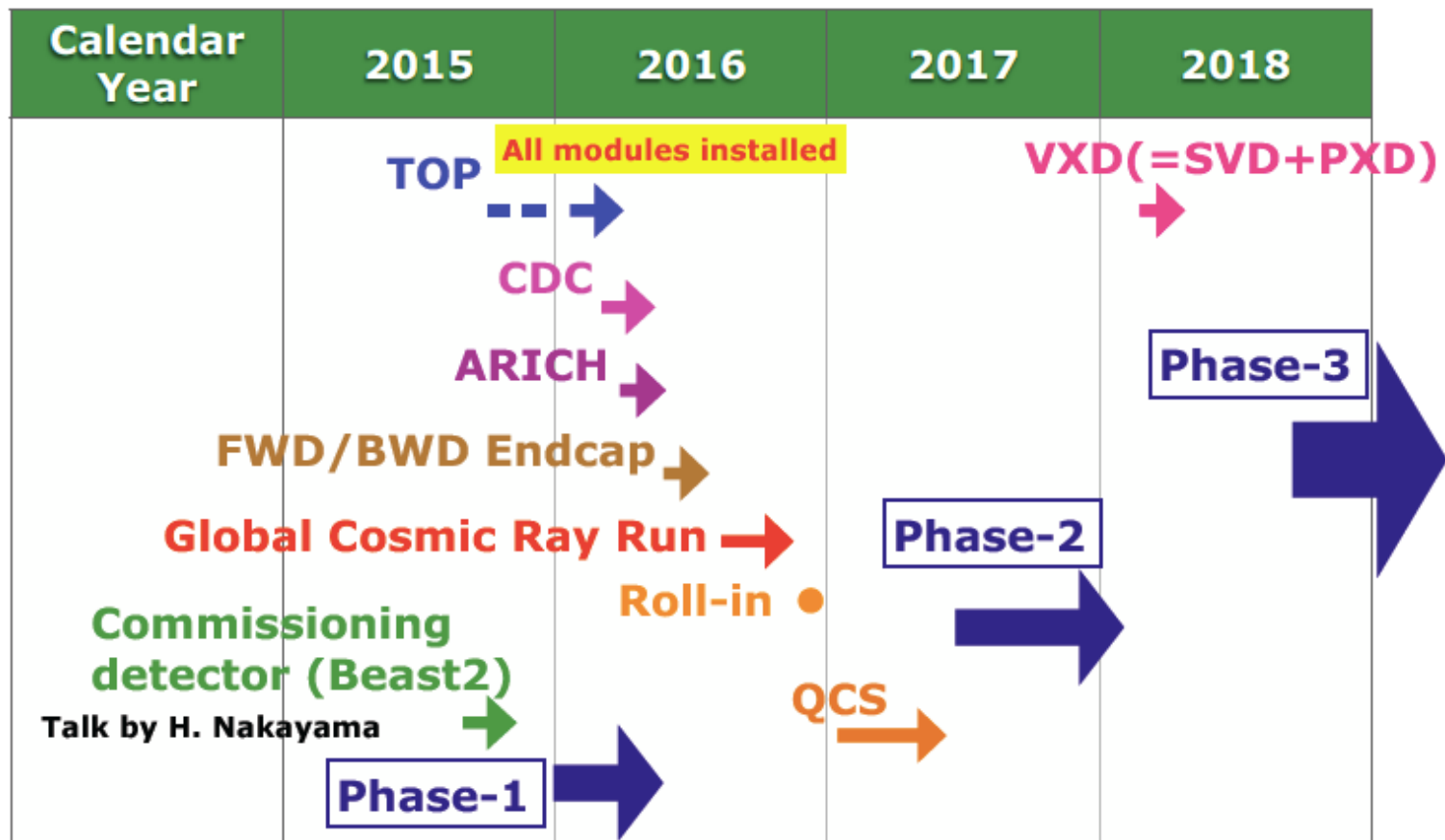
**LHCb can investigate some modes; sensitivity comparable to B factories**

**Healthy competition with LHCb is very important to go forward**



**THANK YOU  
FOR THE ATTENTION!**

# Schedule



BEAST phase 1 2016

BEAST/SuperKEKB & cosmons

BEAST phase 2 Mid 2017- Early 2018

BEAST with Partial Belle II

Full physics Oct 2018-

Full detector